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The Dimming of Fluorescent Lamps and its Application to the Theatre

By J. W. STRANGE, Ph.D., A.R.C.Sc. *(Member)*

Summary

Fluorescent lamps offer a wide range of colour and high efficiency but have not been used for theatre lighting due to the lack of means of controlling brightness. The development of circuits for this purpose is traced from the quick start circuit used for general lighting purposes. The importance of heating the filaments to full thermionic emission and the need for a separate impedance for each lamp circuit is stressed. A range of dimming of over 300 to 1 can be obtained with 2ft. 40-watt lamps. It is shown that relative efficiency of the fluorescent lamp compared with the incandescent lamp is considerably increased when coloured effects are required due to the use of additive light mixtures instead of subtractive filters, the ratios of efficiencies being increased from 2 or 3 to 1 to as high as 40 to 1. Reference is also made to the new lighting effects obtainable.

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(2) LIGHTING REQUIREMENTS FOR STAGE AND AUDITORIUM.

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(5) THE COLOURS OF FLUORESCENT DISCHARGE LAMPS.

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(1) Introduction

The high efficiency of low pressure fluorescent discharge lamps, and the wide range of colour which can be obtained with them, are obvious points which recommend these lamps for use in theatre lighting. The main reason they are not used for this purpose is the lack of a satisfactory method of controlling the light output of these lamps. Statements have been made recently, both in America and in England, that hot cathode lamps cannot be dimmed (1), (2) and that any attempt to do so shortens their life. Using the standard circuits with starter switches, these statements are certainly true, and they have been clearly demonstrated by the trouble experienced during the power cuts of recent winters. Cold cathode lamps are claimed to be better for this purpose. They are reported to stand up to dimming without loss in life and to have a range of brightness of about 20 to 1. That range is, however, insufficient for most stage lighting purposes. The actual requirements for lighting stage and auditorium are not well defined, and the first problem is to determine what these are and particularly to decide what range of dimming is acceptable. After discussing these points consideration is given to the various circuits which may be used and the associated problems which arise from their operation.

The manuscript of this paper was first received on November 16, 1949, and in revised form on January 3, 1950. The author is with Thorn Electrical Industries, Ltd. The paper was presented at a meeting of the Society on February 14, 1950.

(2) Lighting Requirements for Stage and Auditorium

There seems to be no limit to the demands of the theatre. Light and plenty of it is the first essential. Colour, ranging from the most vivid and saturated hues down to pastel shades and whites is the next point. The different colours must be varied smoothly from full-up to black-out, and as smoothly in the opposite direction. The light distribution of footlights and battens must be uniform and shadowless and particularly so from fittings used for illuminating cycloramas. In other cases it must be strongly accentuated as in wing floods or acting area floods. In addition, for many types of stage production intense directional lighting is required; this is produced either by spots or pageants from a bar above the stage or from " perches " at the side, or by front-of-house spots. For a full description of stage lighting technique reference should be made to references (3), (4), (5). General constructional problems are dealt with in a most interesting manner in (6).

A considerable proportion of the lighting requirements of the stage must be provided by footlights, battens and floods the actual amount varying widely for different types of production. The usual design of fitting, whether for footlight or batten, is a magazine type which consists of a row of separate compartments each containing an incandescent lamp of 60 to 150 watts and a reflector.

Coloured light is obtained by fitting colour filters in frames in front of the compartments, the filters being made of gelatine or one of the non-inflammable cellulose materials. A large number of different coloured filters are available and the colours obtainable with incandescent lamps are plotted in Fig. 1. The most economical use

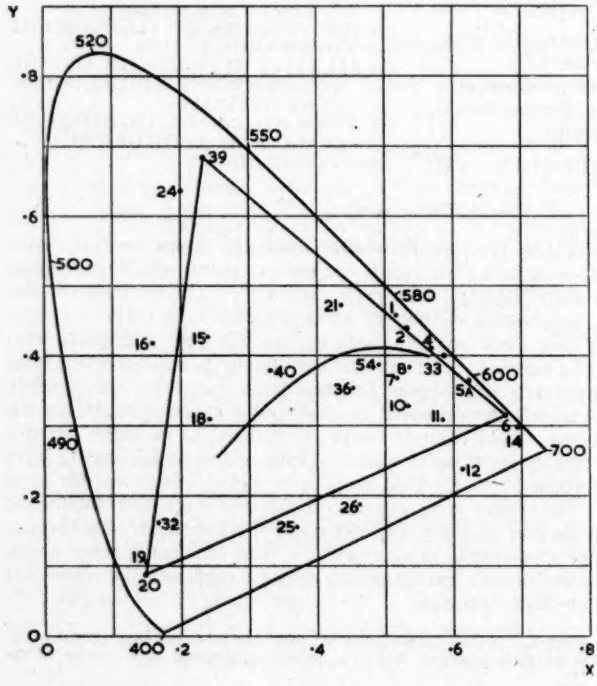

Fig. 1. Colours obtained from incandescent lamps with stage filters.

of power, and the highest intensity for any installation can be obtained by changing the filter to give the colour required, but this is difficult to achieve particularly in overhead fittings in productions in which a number of scenes require different lighting. A common procedure is to use three or four circuits mixing red, green and blue, or other primaries usually with the addition of white. The required colours are then obtained by varying the current in the different circuits. By this means the majority of the colours produced by the different filters can be achieved. If the three filters Nos. 6, 39 and 20 are used, it will be seen from Fig. 1 that all the colours lying within the triangle formed by joining their plotted points can be obtained. Some of the more saturated colours such as 1, 25 and 16 cannot be exactly reproduced by such means and in such cases special filters are still required. How often such saturated colours are needed is a matter of some doubt. It must be remembered that the light is being used to illuminate a scene, and is not viewed direct, so that its colour-rendering (or rather colour-distorting) properties are mainly required. A colour is often, if not always, mixed with another, so that the final result is rarely that of a saturated colour. The stage designer usually has little doubt that the scenery he produces requires mainly white light with some accentuation of certain colours for particular effects.

One problem arising from the use of such four-colour circuits is the difficulty of maintaining colour quality while the intensity is changed. Proportional dimming of all colours is required irrespective of their intensity, and it has been stated that this is impossible to achieve. The problem is complicated by the characteristics of the incandescent lamp, and is concerned also with the design of the dimmers used. It will be referred to again in a later section. The fact that a considerable amount of colour change is tolerated under such conditions is an indication that some latitude is permissible. Some change of colour with intensity is probably desirable sometimes because as is well known the apparent colour of light varies appreciably with change of intensity. For example, the daylight fluorescent lamp gives a pleasant light at about 5-10 lm/ft.^{2}, but for lower intensities, a warmer or redder colour, such as warm-white or peach, is preferred. Another point which also indicates the extent to which a considerable variation in colour is at least tolerated, is the degree to which most filters vary in colour during use, particularly if any scorching occurs. It is quite a common practice to fit a No. 32 blue filter when the final requirement is a No. 18, which as seen from Fig. 1 is a considerable distance away.

From such an accumulation of facts and theories it is difficult to obtain any detailed information of the degree of colour control required. The popular use of a three- or four-colour system is the best indication that the control need not be very exacting.

Information on the range and smoothness of the dimming is more exact because stud type dimmers are very widely used. The number of steps varies, the most common being between 80 and 110. If Fechner's law is taken as a guide to the design of such a dimmer it will be found that each step, in the case of a 100-step dimmer, must reduce the brightness by 5 to 7 per cent. if a range of, say, 300 to 1 is to be achieved; this is considerably higher than the figure of 2 per cent. usually given as the minimum perceptible brightness change for illumination levels above about 1 lm./ft.^{2} [8]. At low levels of brightness the Fechner fraction increases rapidly and undoubtedly helps to ease the problem of smooth dimming. It is difficult to do more than use this experience as a general guide because we are not in practice concerned with one lamp illuminating a known surface, but a great variety of lamps illuminating stage sets of different sizes and colours from a wide range of distances. The point at which the illumination reaches a level of 1 lm./ft.^{2}, and at which the rate of dimming can be increased without noticeable flicker is not easy to establish. A range of 300 to 1 may be taken as a reasonable objective, having in mind the use of the 100-step dimmer.

(3) Dimming Circuits for Fluorescent Lamps

(3.1) Early Stages of the Development

The essential features of the new circuits used for dimming fluorescent lamps can best be explained by tracing the course of their development. First came the demand for more reliable and more rapid methods of starting hot cathode fluorescent lamps than was provided by the glow and thermal switches commonly used for that purpose. Good switches, particularly of the thermal type, will start in 1-3 seconds, and give restriking in 10-20 seconds. Glow switches give quicker restriking but less positive initial starting. There was, nevertheless, a considerable amount of dissatisfaction with the general performance of starter switches, due partly to poor design or manufacture. This dissatisfaction was accentuated by the drops in supply voltage, which were a common occurence during the winters of 1945-47. Thermal switches depend upon the lamp current to hold them open; if it drops, "blinking" results. A change of 10 per cent. in supply voltage produces the large drop of 23 per cent. in lamp current. Glow switches are better, but they become sluggish in operation as the voltage drops, and may reach the point where ionisation does not occur, and the switch fails to operate. The only alternatives to starter switches in common use were various forms of voltage boosting circuits, which, by applying a high voltage to the lamp, caused a discharge to strike, as in a cold cathode lamp. The resulting high voltage bombardment of the cathodes heated them to a sufficient temperature for thermionic emission, and the discharge changed to normal hot cathode operation. The initial bombardment was, however, very bad for the cathodes, and the life of the lamp was drastically reduced. If this was to be avoided hot cathode operation had to be assured within a fraction of a second of the switching on of the lamp supply. The problem therefore reduced itself in the first place to the search for some means of raising the cathodes rapidly to full thermionic emission.

A number of interesting suggestions, usually based upon shunting the ballast, were tried out, but they all added to the complications of the circuit. The only satisfactory suggestion made use of the fact that the full supply voltage was across the lamp before the discharge was established, and afterwards was reduced to less than half that value. The basic idea was the use of a filament transformer with its primary winding connected across the lamp and its two secondary windings connected to the two cathodes. (See Fig. 2.) By suitable design a high initial current rapidly heated the cathodes to the necessary temperature, and when the lamp discharge started, the drop in potential reduced the power loss to a low value.

Early complaints that this so-called "quick start" circuit was bad for the lamps had no justification. They were partly due to the false assumption that the quick start circuit was similar to the resonant circuits. The reverse was true, and there was, in fact, less high voltage bombardment even than in the common switch circuit. In the latter case the rapid opening of the switch produces a high transient voltage which plays an important part in striking the lamp; after an initial failure to strike this high voltage surge is repeated with damaging effects similar to cold cathode operation. Only where effective preheating is obtained is this damage avoided, so that switch design plays an important part in determining lamp life. In the quick start circuit, by its very nature, no attempt is made to strike until the cathodes are at the correct temperature, so that cold cathode bombardment is impossible. This conclusion is borne out by tests. In one typical series using glow switches 50,000 strikes were obtained before lamp failure, while similar lamps in the circuit described above gave 75,000 strikes.

The provision of effective cathode heating was not the only requirement needed to produce an effective quick start circuit. The lack of the high voltage transient means that starting conditions are more critical, and certain additional requirements

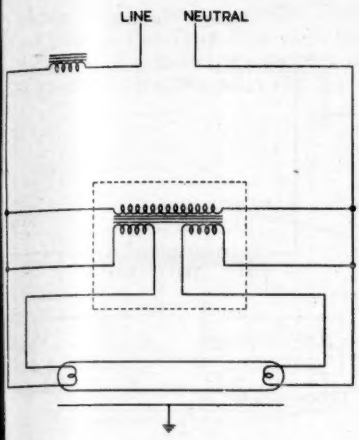

Fig. 2. Quickstart circuit.

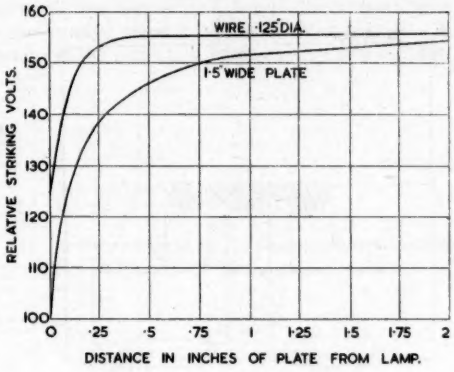

Fig. 3. Relationship between striking voltage and size of adjacent earthed plate.

had to be established by experiment before reliable operation could be claimed. The first requirement was a good earth in close proximity to the lamp. The striking volts of, say, an 80-watt lamp vary between 170 volts and 270 volts, according to the area and distance of an earthed metal plate; the effect is roughly proportional to the capacity between lamp and earth. Relative figures for an 80-watt lamp are given in Fig. 3.

Basically the physical explanation is that there is a capacitative current to earth from the ends of the lamp which causes the ionisation of the lamp to be extended from the region adjacent to the electrodes along the lamp until the whole length is conductive, and the discharge can strike from end to end. The condition of the glass surface can seriously affect this process, and consideration is given to this subsidiary factor in a later section.

After fulfilling the two requirements of effective cathode heating and a closely adjacent earth, excellent starting performances were given by 5-ft. 80-watt, 4-ft. 40-watt and 3-ft. 30-watt lamps. There was a considerable variation of performance among lamps of similar manufacture and it was necessary to grade lamps to ensure good low-voltage operation. This ability of suitable lamps to operate at low voltages was one indication of the possibility of dimming discharge lamps.

The next most important step was the development of the special quick start circuit for operating two or more lamps in series. This arose from the demand for a shorter lamp for domestic purposes and from the suggestion that two 2-ft. 40-watt lamps should be operated on one 80-watt choke. The standard glow switches were useless for such a circuit, and although thermal switches could be used, they were far from satisfactory. The most successful method of operation consisted of a special circuit with an additional secondary winding for heating the centre pair of cathodes (Fig. 4). There is no need to trace in detail the successful application of this circuit; the important point is that a very considerable increase in the range of dimming was obtained. This was particularly noticeable as the line voltage was reduced. The reduction in the striking voltage was not so marked.

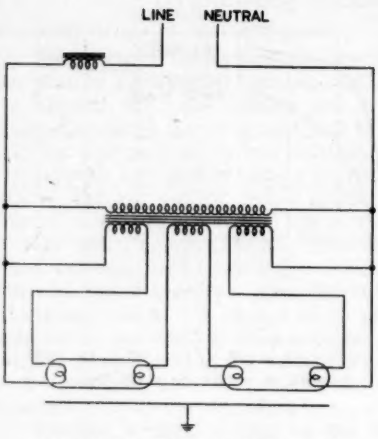

Fig. 4. Double quickstart circuit.

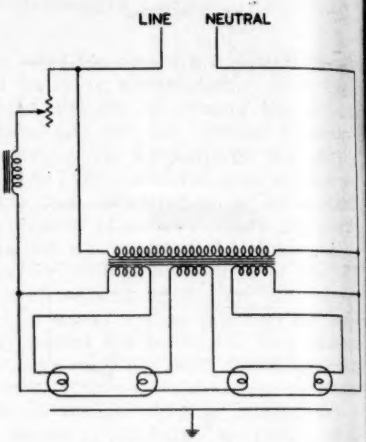

Fig. 5. Dimming circuit.

(3.2) Requirements of a Dimming Circuit

Further study of this and other circuits showed that the limitation of the range of dimming was due to three factors:—

(1) As the line voltage was decreased the discharge current and the current derived from the quick start transformer were reduced and the point was reached at which the cathodes ceased to have sufficient thermionic emission for hot cathode operation.

(2) The applied voltage was insufficient to initiate a discharge although the same voltage might be sufficient to maintain a discharge once it was established.

(3) The drop of voltage across the choke was insufficient to ensure stable operation.

Two additional requirements were necessary to deal with these three factors. The first was that the electrodes must be maintained at emissive temperature over the full range of operation. This could be in a number of ways, one of the simplest being to connect the primary winding of the quick-start transformer direct to the supply and quite independently of the lamp-dimmer circuit. Redesign was needed to give the best results, and this unit is referred to below as the "dimmer quick start." The second requirement was that the dimming must be achieved by the use of a separate variable impedance in series with each lamp, or in the case of series operated lamps such as the 2-ft. 40-watt lamps, with each pair of lamps. The variable impedance was preferably in the form of a resistance although an inductance such as a saturable reactor could be used. Fig. 5 shows a typical circuit for resistance control of a twin 2-ft. 40-watt circuit. The importance of the use of a separate variable impedance as dimmer control results from the fact that by this means the full line volts are applied to the lamp terminals irrespective of the amount of impedance in series with the lamp up to the moment when the lamp strikes. This feature effectively avoids the striking voltage difficulty common to all variable voltage control circuits. Control of a number of discharge-lamps by a common-resistance dimmer is unsatisfactory because the first lamp to strike decreases the voltage across the other lamps.

Besides meeting the striking problem the separate impedance also stabilises the circuit at the point where the ballast volts are reduced to a very low value. In Fig. 6 the voltage drop in different parts of an 80-watt lamp circuit is plotted for different

current values. For comparison the corresponding figures for variable voltage control are given in Fig. 7; in both cases the rest of the circuit including cathode heating is the same. The cause of instability in the voltage control circuit is clear enough. It is possible, as is indicated in Fig. 7, to attain stable operation again at very low currents

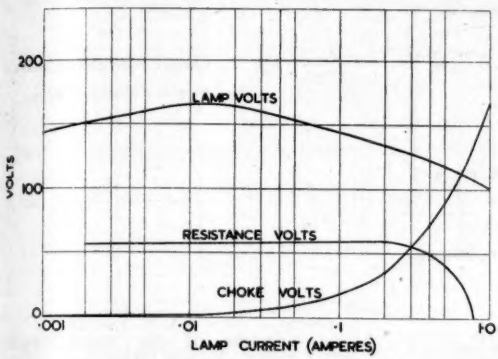

Fig. 6. Lamp circuit characteristics for resistance dimmer.

(about 0.01 amps.) where the positive resistance characteristics of the glow discharge appear, but there is no certain control in the transition region.

(3.3) Summary of the Results

The different stages in the development of this circuit can be followed in Table 1, where the range of dimming obtained by the various circuits is listed. Fig. 8 shows the change in light output from the resistance circuit when a 100-step dimmer was used. This approximates closely to the figures for a Fechner fraction of 7 per cent., which are shown as the continuous line.

Table 1.

Dimming Ranges for Various Circuits.

Circuit		Per cent. of Maximum Light Output	
		Down	Up
		per cent.	per cent.
80-watt Thermal Switch	Variable Voltage Control	70	70
80-watt Glow Switch		15	55
80-watt Q.S. Unearthed		15	100
80-watt Q.S. Earthed		15	45
2 x 2 ft. 40-watt Q.S. Earthed		3	40
2 x 2 ft. 40-watt Dimmer Q.S. Earthed		1	10
2 x 2 ft. 40-watt Dimmer Q.S. Earthed	Separate Resistance Control	<0.3	<0.3

The first column gives the lowest light output, expressed as a percentage of the maximum or " full-up " value, to which the lamp can be reduced by decrease of the applied voltage or increase of the series resistance. The second column gives the minimum figures at which the lamp will strike when the controls are moved in the opposite direction from black-out " up " towards full brightness.

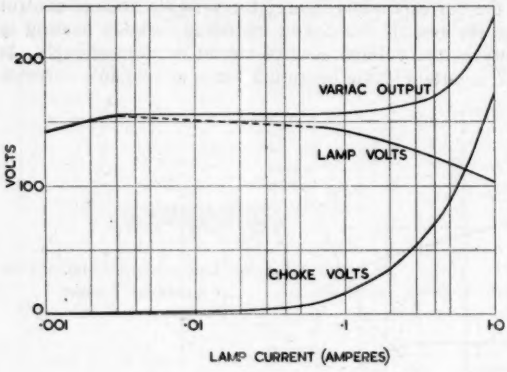

Fig. 7. Lamp circuit characteristics for variable voltage control.

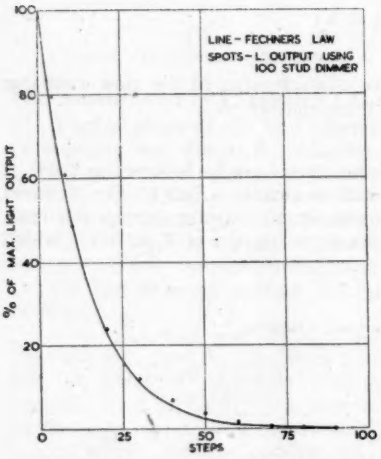

Fig. 8. Light output using 100 stud dimmer control.

Many variants of the main circuit described are possible. The use of a saturable reactor in place of the variable resistance dimmer holds out the attractive possibility of easy remote control but it is difficult to get the full range without excessive size and cost. A measure of control in the supply to the filament transformers is sometimes a useful addition as long as it does not affect the main requirement of adequate cathode heating.

The use of the dimmer quick start and separate resistance control also makes a great difference to the other sizes of lamps. For example, the light output from the 80-watt lamp can be reduced to less than 1 per cent. but for the widest possible range the 2-ft. 40-watt is definitely superior.

(4) Other Characteristics of Low Pressure Discharge Lamps

Discharge lamps are much more complex in their operation than incandescent filament lamps. A major problem in this development of quick start circuits, and particularly in its application to stage lighting, is the difficulty of producing uniform behaviour among these "temperamental" objects. Fully mechanised production is an essential step towards uniformity because production on bench pumps and ageing racks which depend upon the skill and attention of operators is all too prone to variation.

(4.1) The Effect of Humidity

The next most important single factor is the condition of the surface of the glass. This is, of course, dependent to a marked degree upon the humidity and temperature changes in the atmosphere. In Fig. 9 is plotted the variation of striking volts of an

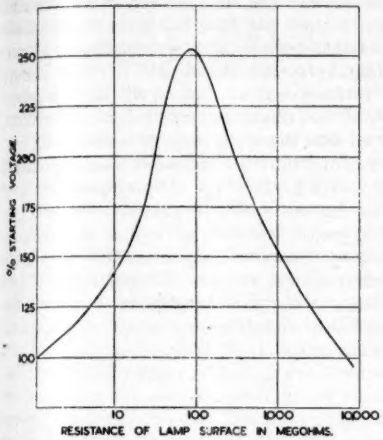

Fig. 9. Relation between striking voltage and surface resistance.

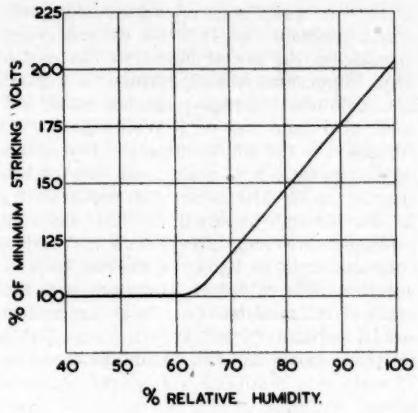

Fig. 10. Relation between striking voltage and humidity.

80-watt lamp with its surface resistance. The range of resistance 10-1,000 megohms which includes the peak of the curve is that associated with humidity conditions varying from 60 per cent. to 100 per cent. saturated. This is also illustrated by Fig. 10. High humidity conditions are not frequent in this country but they occur sufficiently often to make the possible rise in striking volts a serious problem. Contrary to general impression conditions of high humidity are not confined to cold and wet periods. Sudden changes of temperature such as occur in the spring and autumn are the most frequent causes of very high values. Freezing conditions, on the other hand, have usually low humidity. This point may be illustrated by the use of quick start circuits for the lighting of refrigerators. An initial reaction to this suggested that it was taking an unjustified risk but the results have been generally satisfactory.

The explanation of the change of striking volts with the change of surface resistance is difficult. One tentative theory ([7]) is that the surface layer acts as a resistance-capacity network with such a time constant that it tends to decrease the capacitative current to earth which is an essential feature of quick start operation. There are two ways of dealing with the problem. The most satisfactory is to produce a water repellent layer on the surface of the glass. Under conditions of severe precipitation of water from the atmosphere this layer breaks up the surface layer of water into droplets and keeps the resistance at a high value. The other method is to keep the resistance at a low value by provision of a metal strip touching the glass surface along the major portion of the lamp. This is an additional item which does not lend itself to automatic production methods and is very liable to damage. It is reasonably satisfactory for the 80-watt lamp but for the 2-ft. 40-watt lamp under normal conditions it is prone to develop an effect known as "creep start." This is a premature glow discharge which, by dropping the volts across the lamp, delays the initiation of an arc discharge.

(4.2) Krypton as a Gas Filling

The other main variable under our control is the gas filling and its pressure. A full discussion of this point is outside the scope of this paper, and it is in addition a subject about which our knowledge is surprisingly scanty. The use of krypton is a case in point and it is worth some consideration because it brings out one of the main

features of quick start operation. Krypton, before the war, was a very expensive and scarce product. In 1928 the quoted price was £2,000 per litre but due to the great increase in the use of liquid air the cost has fallen heavily and is now about £2 per litre. Experiments with krypton as a gas filling were reported in 1939 [9] but at that time cost was too high to permit much use. Interest was revived in 1948 by a paper of C. G. Found and W. J. Winninghoff [10] which described the substitution of krypton for argon in the 100-watt lamp. It was reported that the watts were reduced to 85 but the lumen output was increased by over 10 per cent. and the lumens per watt increased from 40 to 52. Use of krypton reduces the gas losses in the lamp. These losses are due to the energy imparted by the electrons to the molecules of the gas. If the gas molecules are very heavy, such as those of krypton, less energy is lost to them in collisions than to lighter molecules such as argon. Another feature is that the lamp volts are reduced, which, combined with the other points, appears to recommend it for quick start operation. Trials with krypton in lamps in the British range gave interesting results particularly in the 8-ft. lamp. The losses due to the higher lamp current were relatively small, and full advantage could be taken of the lower lamp volts. A lamp of 75 watts was produced which operated satisfactorily on 230 volts supply and could be started by glow or thermal starters. The unfortunate fact was discovered however that the striking volts for quick start operation were increased not decreased and even the 2-ft. 40-watt lamp which with argon strikes at 135 volts was uncertain in operation at 240 volts.

For an explanation we must turn to the main metastable levels of the rare gases. These are as follows:—

Rare Gas.	*Excitation Potentials.*	
Neon	16.6	16.8 e.V.
Argon	11.6	11.8
Krypton	10.0	10.6
Xenon	8.4	9.5

In the case of argon, both the main excited levels have energies greater than that required to ionise mercury, i.e., 10.4 e.V., and a proportion will produce such ionisation. On the other hand, it will be seen that one of the two lowest krypton levels lies below the ionisation level of mercury, and it may be assumed that all this energy is wasted. This loss of energy which arises from the use of krypton makes a serious

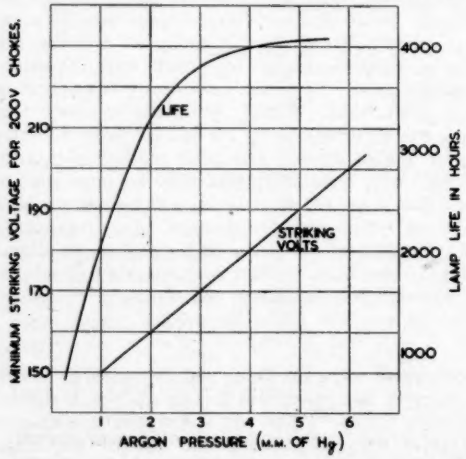

Fig. 11. Relation between gas pressure and striking volts and life.

difference to the degree of ionisation during the starting periods. In inductive circuits when glow or thermal switches are used the quick break of the switch produces high transient voltages of about 700 volts, and this is sufficient with a limited degree of ionisation to initiate the discharge. In the quick start circuit, on the other hand, the peak value of the voltage does not exceed 300 volts, and the change from argon to krypton makes all the difference to effective starting.

The other rare gases, xenon and neon, are no better for the purpose. Xenon will increase the striking volts for the same reasons, and it offers little further improvement of the efficiency. The gas losses with neon are increased considerably.

The other main variable in lamp design which controls quick start operation is the pressure of the gas filling, and here something can be done to improve the characteristics of lamps. In Fig. 11 are given the striking volts for a range of 80-watt lamps made with argon filling pressures ranging from 1 to 6 mm. of mercury. The striking volts are certainly improved by reducing the pressure, but at the same time the average life of the lamp, as is also shown in this figure, is reduced, so a compromise has to be reached. If the present life of 3,000 hours is to be maintained, filling pressure must be kept above 2 mm.

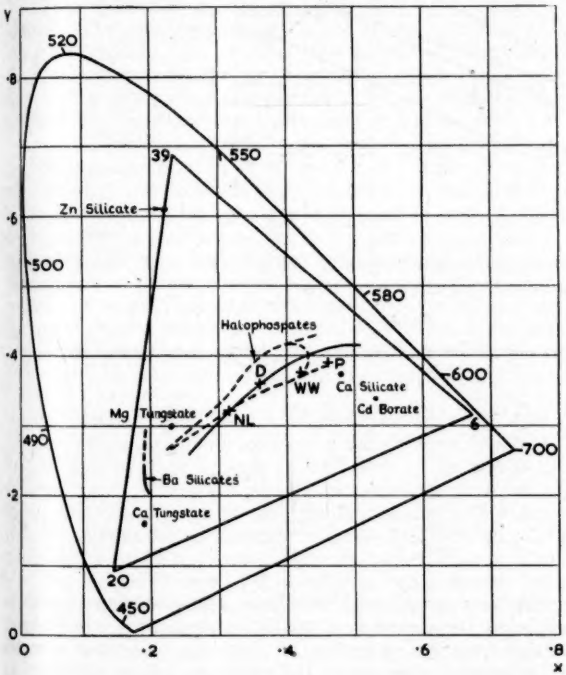

Fig. 12. Colours obtained with fluorescent lamps.

(5) The Colours of Fluorescent Discharge Lamps

The wide range of colour filters available for stage lighting has already been illustrated in Fig. 1. In that figure is given a triangle showing the colours obtained by mixtures of the light through three typical "primary" filters, Nos. 6, 39, and 20. This same triangle is also in Fig. 12, where the main colours given by fluorescent lamps

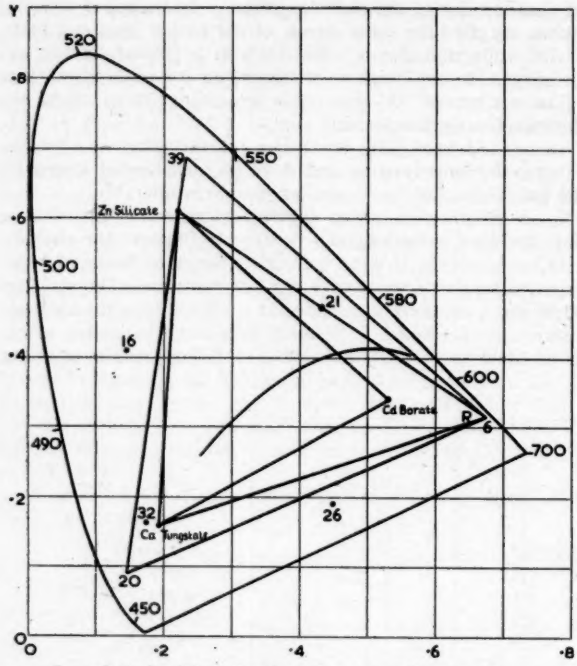

Fig. 13. Different three colour systems.

are also plotted. The chromaticity co-ordinates of some of the single phosphors are given in Table 2, and also the nearest equivalent filter.

Table 2.

Chromaticity co-ordinates of some phosphors and nearest equivalent filter.

Phosphor	*x*	*y*	Equivalent Filter
$CaWO_4$	.190	.160	32
$MgWO_4$	.230	.300	18
Zn_2SiO_4.Mn... ...	.225	.610	24
$CaSiO_3$.Pb.Mn ...	.480	.375	54
$Cd_2B_2O_5$.Mn ...	.530	.340	10

The colours of these phosphors can all be altered over a limited range, either by the addition of an activator or by the variation of the activator content. In addition to these phosphors there is also a number of groups of phosphors of a more complex nature which give colours covering a wide range, the variation being achieved by alteration not only of the activator contents but also of the proportion of the base materials. Of these phosphors one group, the zinc beryllium silicates, has been abandoned. Two other groups may be mentioned, the halo-phosphates and barium silicates. The approximate range of colours available for these two groups are also shown in Fig. 12.

Out of the wide range of colours thus made available by suitable manufacture or

mixture some standardisation is slowly being achieved, and the lamps made for general lighting purposes can now be grouped into four main classes:—

(1) Daylight (including Natural).. about 4,500 deg. K
(2) Warm-white ..... about x 0.42 y 0.38
(3) Northlight ..... about 6,500 deg. K
(4) Peach ..... about x 0.46 y 0.39

Of these, daylight (4,500 deg. K) is probably the most suitable for the "white" circuit, if a four-colour system is required for stage lighting. The choice of the other lamps to be used is a more difficult problem. Colours anywhere within the area circumscribed by the plotted points can be achieved by mixtures of the phosphors. Except for special purposes, this would be a hopelessly cumbersome process both for the lamp manufacturer and the stage producer. The special advantage of the fluorescent lamp is, however, that the coloured effects and the "whites" are both achieved by the additive mixing of light. In all previous systems using incandescent lamps a subtractive process using filters was necessary, and a marked drop in efficiency resulted. The total amount of light available was also restricted, having in mind the usual power and space limitations.

Two alternative groups of lamps have been mainly used in trials of the new system. The first consisted of lamps made with zinc silicate, cadmium borate, and calcium tungstate. The second was the same, except for a red filter coat added to the cadmium borate lamp, or alternatively a similar filter coat with a calcium silicate lamp. The two groups are plotted in Fig 13 with the triangle from Fig 1 and some of the fairly saturated filters also, and it will be seen that only a few of the latter are excluded from the mixtures obtained by the second group.

A problem common to all systems in which colours are achieved by mixture is the difficulty of maintaining the same colour as the intensity is changed. For example, if the light illuminating the scene is required to be a "warm-white" it may be obtained by reducing the intensity of the green light to a quarter and the blue to a half and by having the red at full intensity. If the three dimmers controlling these lamps are then moved at the same speed to zero the colour will change first to purple and then to red. A master dimmer in series with the others has been proposed for incandescent lamp circuits and gives some improvement, but it is not applicable to fluorescent lamp circuits of the type described. An alternative mechanical device has been developed, and its ability to achieve the required control can be demonstrated.

(6) Relative Efficiencies of the Incandescent and Fluorescent Systems

So far we have been concerned mainly with applying fluorescent discharge-lamps to problems of stage lighting and not with comparing them with corresponding incandescent units. The point which has attracted the most attention from producers so far has been the *quality* of the lighting obtained with fluorescent lamps. Some attempt will be made in the next section to assess this somewhat intangible feature. The other principal point of difference is, on the other hand, one of very concrete importance.

The electrical load of a theatre is inevitably one that does not qualify for the most favourable supply charges. The predominant feature is a very high maximum demand for short periods, and the management is often faced with the difficult choice between a maximum demand basis of payment which may be blown sky high by one enthusiastic producer putting on a Christmas pantomime, and an excessive flat rate. Economy is, therefore, a major consideration in the theatre.

The comparison between the two systems will depend on a number of variables such as lamp voltage and colour. The efficiency of the incandescent lamp increases as the wattage increases, but the 150-watt lamp may be taken as typical of the size normally used, with an average efficiency of 12.5 lm./w. The use of a filter reduces this figure by a varying amount according to colour. The transmission factors of a

number of commonly used filters are listed in Table 3. If we take Nos. 6, 39 and 20 as a representative group of the filters used it will be seen that the efficiency figures fall to 2.4, 2.7 and 0.4 lm./w.

Table 3.

Filter Transmissions.

No. of Filter	Colour	Per cent. Transmission
4	Medium Amber	76.0
5a	Deep Orange	43.0
6	Primary Red	19.0
12	Deep Rose	9.5
15	Peacock Blue	31.7
16	Blue Green	21.0
18	Middle Blue	16.0
19	Dark Blue	3.4
20	Primary Blue	1.1
21	Pea Green	62.0
24	Dark Green	21.4
25	Purple	3.7
26	Mauve	7.5
32	Medium Blue	4.3
39	Primary Green	22.0
40	Light Blue	32.0

The efficiency of fluorescent lamps also varies with size and loading. In general short lamps and those with a high current density are less efficient than long lamps and those with a low current density. The 2-ft. 40-watt and 4-ft. 40-watt are typical of the two extremes. For auditorium lighting or other applications where the full range of dimming is not required we have a free choice of lamp, but for the more exacting requirements of the stage we must choose the relatively inefficient 2-ft. 40-watt lamp

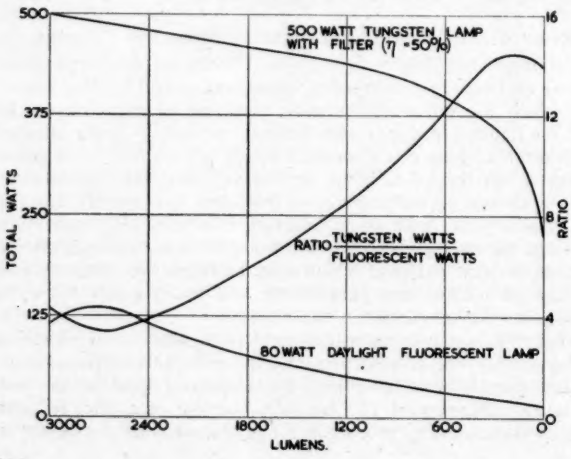

Fig. 14. Comparison of efficiency of lamps during dimming.

with its average efficiency through life for Daylight of 26 lm./w. The corresponding figure for the 80-watt lamp is 34 lm./w., and for the 4-ft. 40-watt lamp 38 lm./w.

If we compare an incandescent lamp without filter with a fluorescent lamp it will be seen that there is a gain of between 100 and 200 per cent. in efficiency, according to size. The advantage of the fluorescent lamp becomes very much more marked when a change is made to coloured lamps. Although the efficiency of the powder is lower except in the case of the green phosphor, the corresponding efficiency for incandescent lamps with filters is reduced to a far greater extent. The average efficiency figures for the second group of lamps listed on page 123 are 16, 31, 10 lm./w. for the blue, green and red 2-ft. 40-watt lamps. The corresponding figures for incandescent lamps with filters are 0.4, 2.7 and 2.4 lm./w. The ratio of efficiencies, therefore, increases from 2 or 3 to 1, to 40, 11, and 4 to 1. That is not the whole picture, for the behaviour of the two types of lamp differ widely when " on check," i.e., in the dimmed condition. The incandescent lamp reaches " black-out " when the current passing through is reduced to half, so that irrespective of the amount of dimming the load is never reduced below half the full value. The efficiency of the incandescent lamp also falls rapidly according to the sixth power of the current; which is another factor tending to keep the total consumption at a high proportion of the connected load.

On the other hand, the brightness of the fluorescent lamp is very roughly proportional to the current and reaches its lowest value with a current about 2 m.a. In Fig. 14 a comparison is made between incandescent and fluorescent lamps, taking as a starting point the watts required to produce 2,500 lumens of " white " light, and plotting the change in watts consumed as this is reduced to zero. The watts consumed in the filament transformer and choke have been added to the lamp and dimmer watts. The ratio between the two sets of figures is also plotted, and it will be seen that a further substantial increase from a ratio of 4.4 to over 10 occurs in practice.

This is the main economy arising directly from the technical advances, but there is another point of very practical importance—the saving on the cost of filters. Incandescent lamps run at a high temperature, and the filters sooner or later warp, split, or change in colour. As stated above, it is a common practice to fit a No. 32 blue when a No. 18 blue is required in order to allow for this instability. The fragile nature of the filter is particularly embarrassing with the deeper colours such as No. 19 blue; due to the low transmission figure (less than 2 per cent.) of this filter a high wattage has to be used, and if a split occurs when, say, it is being used to light a cyclorama a streak of white light of apparently searchlight intensity can be seen.

(7) Applications to Lighting of Stage and Auditorium

The system was first shown to the public early in 1949, one of the first occasions being a meeting of the Manchester Centre of the I.E.S. Since then the general interest in its possibilities has increased rapidly, and a number of standard designs have been prepared. One four-colour unit using 2-ft. 40-watt lamps is shown in Fig. 15. This is readily adaptable for use as ground row, batten, or footlight. An interesting feature of this unit also illustrated is the special safety holder. This is used for general lighting purposes, but is of special importance here because it holds the tube firm in spite of the most violent shocks. In Fig. 16 is shown another design for two colours only using 5-ft. 80-watt lamps.

The calculated efficiencies of the units have been tested in practice. One such opportunity arose during the lighting rehearsals for the " Olympians " at the Royal Opera House, Covent Garden, when the comparative efficiencies of the fluorescent and incandescent systems for producing the colour of No. 18 blue on the cyclorama was

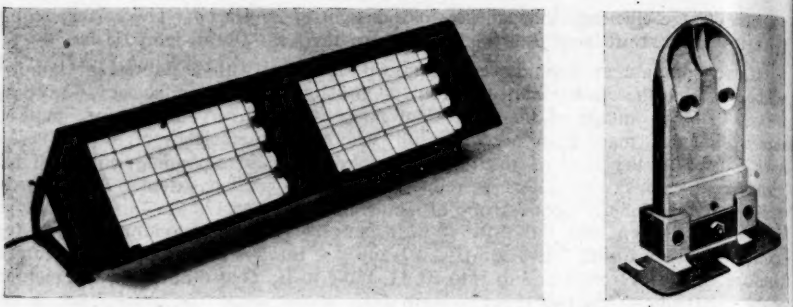

Fig. 15. Four-colour 2-ft. 40-watt unit and safety holder.

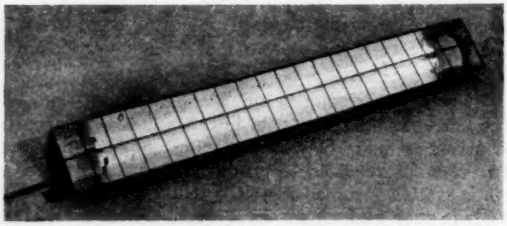

Fig. 16. Two-colour 5-ft. 80-watt unit.

tested. One ground row of fluorescent units with a total load of about 5 kw. effectively balanced 50 kw. from the fittings comprising the mid-cyclorama bank.

The main importance of the various trials during the past year was not concerned with economy, although that was clearly demonstrated. The final arbiter in matters of stage lighting is usually the producer; if he can obtain the full range of colour and control that he requires, any system can obtain a provisional "blessing," but for enthusiastic support the system must achieve new effects and widen the range available. There have been reactions of both degrees to the fluorescent system.

What are the new possibilities? They must, of course, be worked out mainly by the producers, but we hazard a few general suggestions. The colours used in the past have been limited to the filters available unless the relatively inefficient three-colour system was used. Now there is a much greater range available. This may or may not be an advantage, and it will certainly yield of its best only to skilled producers. One point is, however, certain; the range of intensity, particularly in the blues, is greatly increased for most installations. It was because of this that the system was applied first in a large theatre, for the production of "Careless Rapture" at the Lewisham Hippodrome. The quality of the "whites" obtainable has often called forth favourable comment, but there is here a curious point that white, as such, is not often used on the stage; the reason may be the cold effects produced at low intensities, though this may be altered with the higher intensities now available.

Leaving questions of colour, one certain advantage, particularly in the small stage, is the great uniformity and lack of shadow which results from the long, almost unbroken, line of light. There is no further need for the ugly blobs of light which

so often fall on actors or on curtains close to the footlights. Considerable advantages from the actor's point of view are the great reductions in heat and glare.

(8) Conclusion

A high proportion of this paper has been directed to the application of this system to stage lighting because this makes the most exacting demands. Much wider use may be made of it for the lighting of cinemas and auditoriums, and for shop windows and other forms of display lighting, where dimming or "animation" of the coloured effects is required.

In conclusion I wish to express my thanks to the directors of Thorn Electrical Industries for permission to publish this paper, and to my colleagues for help in preparing the material.

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Discussion

MR. E. E. FARADAY said that in the theatrical world there were many different personalities and ideas, and it was refreshing to see new methods, new applications and possibly new techniques in the lighting of stages. He had seen this evening some very interesting things which he was sure were the beginning of great things. The author had dealt mainly with footlights and battens and these were important applications, for they played an important part on the stage to-day. Their job in life was to create an atmosphere at the right time and in the right place so that the emotions of the people watching the show could be built up and the dramatic point emphasised. One of the most important things about the emphasis of that dramatic point was that the audience should not know, or not think or stop to think, what was going on. In other words, the lighting had to be subservient to the plot. It had become increasingly common among producers to utilise batten and foot-lighting to provide an atmosphere, a sort of framework into which were put living people in order to complete the picture. The demonstrations of stage lighting which the author had given were very beautiful: even so it would not be long before an audience would tire of lighting alone and ask when the artists would appear, because the play was the thing. Therefore, the producer had to make a very definite effort to put the artists into the picture and emphasise those artists in various ways against the background or in the framework which he had created.

The author had stated that his demonstrations were confined mainly to foot-lighting and batten lighting but the demonstrations indicated that he must have

thought very seriously about the method of high lighting and making people stand out against the background. The high intensity lighting of the acting area was becoming increasingly important and Mr. Faraday did not think it was far wrong to say that to-day something like 50 per cent. of the total connected load on the modern stage was taken up by the acting area and spot lighting. Unfortunately it was still necessary to rely on tungsten lamps for that and if somebody would come along with a novel light source that fulfilled these requirements, it would be a very useful addition. If the high lighting of the acting area was of such importance—and personally he believed it was—then it must be important to know the economic value of this new development in batten and foot-lighting. Could the author give some idea of the costs of the equipment? For example, could the author give a figure, such as the cost of a single 24-ft. batten complete with the necessary control equipment, so that those concerned could evaluate the comparative costs and determine how long it would take to recover the capital cost. It was important to remember that the theatre only operated for a very few hours. Something like thirty hours a week was the average and on that basis equipment must be reasonably economical to purchase, instal and run.

The paper emphasised shadow-free lighting, but Mr. Faraday was afraid of that term. Shadow-free lighting was most uninteresting. Everybody looked flat and it was essential to introduce shadow somewhere. It was true that the stage was largely artificial but every endeavour was made to get some human interest. That was where high intensity sources of illumination came in and producers were aiming more and more to use shadow so that the profiles of the people on the stage should be interesting.

The point was made in the paper that a producer often called for a No. 32 blue filter when the final requirement was a No. 18. Mr. Faraday would like to meet that producer because his experience had been that where a No. 32 had been employed under conditions in which a No. 18 was demanded, the producer quickly had something to say.

In conclusion he congratulated the author on his work and said that such developments were very much needed. Expressing the hope that his criticisms had not been destructive he said he would like to remind the author that on the stage they were not allowed to use lighting for lighting's sake. It must be subservient to the plot, and subtlety was the key-note. All stage lighting must be the tool of the producer, and the producer must never be the slave of the stage lighting equipment.

MR. H. R. RUFF said that after the really excellent survey and demonstration of the problem that Dr. Strange had given it was a little difficult to accede to his request that the discussion should be controversial. The dimming of fluorescent lamps, both white and coloured, was an art which he believed would take its place for special decorative lighting as well as in the theatre. Dr. Strange dealt fully with the theoretical aspects of dimming, but it might be said that he had shown but little progress in the main difficulties involved in the practical solution of the problem, the bulk control of a number of lamps with the minimum of wiring, this control being sufficient to reduce the lamp current to a very low value.

The question of this low current was mentioned in the paper but perhaps not quite sufficiently stressed. Owing to the fact that the luminous efficiency of fluorescent lamps is maintained and even slightly increased as the current is reduced it is necessary to reduce the current to a very great extent to obtain a high degree of dimming. From this point of view the fluorescent lamp started at a disadvantage when compared with the incandescent lamp. The latter lamp could be dimmed with a 50 per cent. reduction in current; in the case of the fluorescent lamp to reduce the light output to 0.3 per cent. it was necessary to reduce the current to about 0.25 per

cent. That presented a problem in equipment and had considerable bearing on the request of Mr. Faraday for a comparison of costs.

For the dimming of cold cathode fluorescent lamps it was simply necessary to maintain a sufficiently high supply voltage to enable the current to be reduced sufficiently to give the required degree of dimming. In hot cathode lamps it was necessary to maintain the lamp cathodes at emission temperature while carrying out the same process. He had been concerned with an interesting dimming problem during the war where the lighting from two 2-ft. 20-watt lamps was required to be faded out for animated camera work for mechanism studies. A circuit using a resistance dimmer similar to the one mentioned by the author was used, cathode heating was provided and the circuit was arranged so that as the current through the two lamps in series was reduced a partial resonance came into action raising the circuit voltage. By this means, dimming to a value of 0.1 per cent. was satisfactorily achieved. The use of fluorescent lamps had the advantage that uniform lighting with a high photographic efficiency was obtained, with a good colour rendering and a maintenance of the colour quality as the light intensity was reduced.

The main problem was to simplify, by bulking, the dimming equipment. One really wanted, if possible, to have a single dimming point with the minimum amount of wiring between this point and a considerable number of lamps. He believed that such a system had been employed in an installation of coloured fluorescent lamps at the British Rayon Institute where the use of saturable reactors enabled a single additional circuit to control a number of lamps. There still remained the problem of additional losses in these reactors. He had been carrying out some interesting experiments in trying to get bulk control by the use of series circuits. It was hoped to publish details shortly of one installation using such a series system so that those interested could consider the method adopted for themselves.

The operation of fluorescent lamps on instant start circuits was perhaps rather subsidiary to the main paper. The author had mentioned American developments of instant start circuits using lamps with activated cathodes suitable for cold starting. Coincident with these developments, work in this country was proceeding along the lines that, with our higher 200/250 V. supply mains, it should be possible to obtain reliable starting of hot cathode lamps at such voltages. For that purpose it had been necessary to use the transformer heating instant start circuit of the type demonstrated that evening. Mr. Ruff could confirm that with properly designed circuits under normal temperature and mains voltage conditions, the behaviour of suitable hot cathode lamps was quite satisfactory. The problem of introducing this circuit was that for satisfactory operation it required a slightly more expensive lamp and auxiliary equipment. The queries that arose concerning the possibilities of such circuits damaging lamps were probably due to the early introduction of some circuits giving inadequate preheating, and the erratic behaviour of standard fluorescent lamps under conditions of high humidity.

Referring to Fig. 9 in the paper he asked whether in fact this was obtained from additional data or whether it was a modified presentation of the data given by Thayer and Hinman to which the author had referred. The data seemed to be more directly applicable to the cold starting lamp. The use of a 1 megohm value as the lower resistance limit could hardly be applied to lamps on the British market. The curve indicated that still better striking might be obtained with resistances greater than 10,000 megohms. His own data had shown that the curve should become asymptotic around this value and that the striking voltage was rather higher than that obtained with resistances below 1 megohm.

Similarly from his measurements, the data in Fig. 3 seemed to refer to cold starting lamps. With cathode heating the effect of capacity did not appear to be as important as the control of lamp wall potential, and a wire as small as 0.001 ins. in

diameter had been found under normal temperature conditions to be as effective as a wide plate with both in contact with the lamp. Larger strips are generally employed simply from the point of view of mechanical reliability.

Finally, Mr. Ruff agreed with the author's view on the need for an exchange of views as to the degree of dimming necessary for various applications. Virtually any degree of dimming could be obtained but the greater the degree of dimming the greater the cost. Information on this matter would greatly help manufacturers to give satisfactory service with the minimum cost.

MR. APPLEBEE said he noticed in the printed paper that the author says "Light and plenty of it is the first essential." No doubt Dr. Strange would agree that it is also essential that it be of the right type and in the right place.

He did not agree that the light emitted from the footlights and battens should be uniform and shadowless. He said that Appia, who was the first producer to advocate the use of stage lighting for other than mere visibility, described the footlight as "the monstrosity of the modern theatre"; his reason was of course that in those days the footlight consisted of a long line of lamps as close together as possible which gave the line of light that Dr. Strange said was the feature of the fluorescent type of footlight It was not until use was made of the magazine type of footlight with lamps and reflectors for each colour at about two feet apart that the flatness of objects disappeared when illuminated by the footlight. They had in fact become semi-directional and the light being directed from two or three sources spaced apart helped to make the characters three-dimensional. Add to the bend of light recommended in the fluorescent type the fact that the glass tube is diffused and we are worse off than we were in Appia's days. Very seldom is diffused light required from the footlights.

The same statement applied to the batten, which must cover the backcloth evenly but which must also be semi-directional like the footlight when used for other purposes such as lighting the acting area or a set of draperies. Light on draperies must show the folds and pleats sharply; the spectator at the back of the gallery is a long way off and the three-dimensional effect must be accentuated.

He agreed with the remarks of Mr. Faraday, that in the modern play battens are becoming of secondary importance and in many productions are dispensed with altogether. For example in the play "A Streetcar Named Desire" 150 individual directional units are used, but only two battens, and in "Death of a Salesman," 168 individual units and two battens are used. In both plays the battens illuminated backcloths.

He thought that the fluorescent lamp was, however, useful for the cyclorama when the colour question was at the moment still a problem.

Dimming, particularly for a cyclorama, must be free of the slightest flicker or jump.

MR. J. N. BOWTELL said that whilst the author had given a very interesting and lucid account of this subject he felt there were a few remarks that might be added on the history and background of dimming.

He had in mind not only metal filament lamps which had been in use for dimming installations for 50 years or more, but also cold cathode dimming installations. It was perhaps not so fully realised that three-colour dimming systems had been in use for 20 years in ballrooms, lounges of ships, etc., and that cold cathode fluorescent tubes had been used in such schemes from the mid-thirties onwards. The author had stated that the dimmable range of cold cathode tubes was about 20 to 1, which was perhaps true for neon-filled tubes but not for mercury-filled tubes which could be dimmed over at least as great a range as main voltage tubes and with rather simpler gear.

It was interesting to note that the instant start circuit mentioned in the paper as the

jumping-off point for the dimming circuit is closely similar to that used with low-pressure floodlighting lamps for many years before the war.

As regards the colour of lamps for stage use, Mr. Bowtell did not quite understand the author's preference for less saturated colours. It seemed to him that three fully saturated primaries were preferred by the stage people on which to build up their effects, and some more information on that point would be valuable.

Mention was made in the paper of krypton as a filling gas, but it had poor starting properties and he asked if this gas had any real significance in regard to dimming.

MR. C. DYKES BROWN said he had been interested in the reference in the paper to the need for a separate resistance control for each lamp; this must lead to a complicated installation where many lamps were involved, when compared with the system of control used in the past for tungsten lighting. It was probably generally known now that the whole of the lighting of the Chamber of the new House of Commons was to be by fluorescent lamps, some hot and some cold cathode. After what had been said in the paper and discussion this evening it would be interesting if he stated that one circuit in the main chamber would consist of 72 hot cathode lamps and that the whole of the 72 lamps would be dimmer controlled by one resistance.

MR. F. P. BENTHAM said that all stage lighting equipment, even flooding units such as battens and footlights, must give accurate distribution and location of light. It was not sufficient to hang a batten over the proscenium and allow light to flood indiscriminately.

The main light from that batten would have to be directed on the actors and only a secondary beam on scenery or masking borders hanging adjacent to it. Such distribution characteristics from a fluorescent lamp would involve a great increase of the batten size in order to accommodate suitable reflectors and hanging space was vital over the stage.

Even distribution across the stage had often to be avoided and the compartments of a tungsten batten or footlight fitted with graded colours ranging from, for example, a pale pink to a deep rose from left stage to right. Such grading in a footlight might be compensation for overhead directional and localised light from large power single lamp units.

The whole development in this country for the past 20 years or so, and longer on the Continent, had been towards those latter units—1 kw. or 2 kw. adjustable beam spotlights and sharp cut-off high intensity narrow beam floodlights. They formed the major part, sometimes the whole, of a modern stage installation. Using them the actors and scenery could be lit with localised light from any direction.

The fluorescent lamp *in its present form* could only be considered for the auxiliary flooding equipment; equipment in which high intensity would often be detrimental to the main stage lighting. Footlights, for example, were far too bright already; more shows were spoilt by too much footlight than by too little.

Only for cyclorama work did the present fluorescent lamp have a real contribution to offer. But even there lamp efficiency must not be confused with working efficiency Cycloramas were not often used and when they were, few shows would require anything but some blue sky tints. To give a full range of blues from fluorescent lamps a three-colour system was essential. The outlay on all this equipment, often completely or partially inactive, would have to be taken into consideration when discussing relative efficiencies.

There was a further point: all stage apparatus was supplied through plug connections; this gave maximum flexibility and interchangeability in positioning equipment. Fluorescent lamp dimmer points and wiring were special, dedicated to one type of unit.

To sum up, Mr. Bentham was anxious that one of the magic words of to-day—

fluorescent (the others were electronic and atomic)—should not confuse the issue for non-technical theatre people. Only after the main stage equipment with a really up-to-date comprehensive control board had been purchased should the luxury of fluorescent lighting for special applications be considered. If this were clear he gave the fluorescent lamp a welcome in the theatre but reserved a much greater welcome for a dimming compact source discharge lamp, if and when produced.

MR. C. J. MISSELBROOK said that whilst he knew nothing about stage lighting beyond what he had heard at this meeting, there was one important point that appeared to have been overlooked, and that was the question of heat. He was under the impression that the amount of heat from footlights was a serious disability to actors on the stage, and that seemed such an important point in favour of the fluorescent lamp that he was surprised that the author had not mentioned it.

Commenting on a statement that a very small amount of light leaking on to the stage could, on occasions, completely destroy the effect for which the producer was aiming, he said that, as he understood the circuit, the electrodes were always operated at full supply current. Thus when the lamp was dimmed down to a low brightness, full electrode heating would still take place, giving an appreciable amount of light on the stage.

He was not clear where the control gear was placed in this system, whether it was in the footlights and battens themselves or whether it was remote. If it were in the footlights was not there the danger of noise? There was an inherent hum in all electrical equipment of this type, and with 24 chokes in a 24-ft. batten the noise might prove quite troublesome. Also, was there any danger of poor starting due to the presence of dirt on the lamps? It would seem to be a very difficult problem to keep lamps clean, especially in footlights, and if the operation of the lamps was susceptible to dust on their surface then considerable problems might arise.

MR. HILLING asked for more information as to the relative efficiency of the two short lamps and the one long lamp, to which reference had been made by the author. He also referred to the fluorescent units used above the lecture table in the meeting hall. There was a wire mesh in front of the lamps and he wished to know whether that was for protective purposes or to give more stable dimming at the lower range.

MR. R. R. HOLMES said that no mention had been made of the stroboscopic effect that might be associated with fluorescent lighting on the stage where dancing and other forms of motion were concerned. Had the author any experience of that? He also queried the effect of fluorescent lighting on coloured materials on the stage. The majority of costumes and make-up involved coloured objects, and it was very important in matching fluorescent lighting with equivalent tungsten lighting to know that the colour resultant would be the same.

MR. C. E. WILLIAMS said there were several points in the paper which might be further discussed. In the circuit which incorporated a choke and variable resistor in series with the lamp, and a filament heating transformer with primary directly across the supply mains, there was some danger that, with a constant external current supplied to the filaments, excessive cathode heating would occur when the arc current attained its full value, with resulting short lamp life. This might be overcome by adopting a compromise value of filament heating current, but such a course might well make lamp starting difficult, since the starting voltage was known to rise rapidly as the initial filament heating was reduced. Moreover, lamp life difficulties might then occur due to insufficient electron emission before starting. He suggested, also, that the

phenomenon of "creep start" to which the author referred might well be associated with such a condition of insufficient filament heating.

He was puzzled by the author's conclusion that 2-ft. 40-watt lamps were most suitable for an extended range of dimming. From personal experience he had found that the performance of all of the lamps in the normal range of sizes was very similar in respect of the diminution of arc current which was possible. He ventured to express a preference for the longer lamps since the proportional effect of the residual glow of the filaments under dimmed conditions was less and could be made negligible by obscuring the ends of the lamp.

Another point was the difficulty of securing control in the system which the author advocated. It was clearly best in situations where only a few lamps were to be dimmed, but for the theatrical application, where many lamps were to be controlled, it necessitated the use of what must be a very bulky and elaborate mechanism for ganging the many separate resistors required. Moreover, the lead from each resistor to its lamp might possibly have an appreciable capacity to earth, which would effectively appear across the lamp, in which case, the lamp stability and starting might be adversely affected in the dim condition, due to the high impedance of the circuit.

In the circuit that had been described by the author, no mention had been made of radio interference suppression capacitors which, in normal circuits, were connected across the lamps. Perhaps these had been omitted owing to difficulties concerned with stability. The problem of the suppression of interference in these dimming circuits appeared to be difficult.

The AUTHOR, replying to the discussion, said that in presenting his paper he had tried to make clear that the very nature of a fluorescent discharge lamp prevented its use as a concentrated light source, and in consequence such lamps were limited to the many applications now filled by footlights, battens, and wing floods. Messrs. Faraday, Applebee and Bentham had each in turn discussed this point, and their comments were mainly directed to supporting that conclusion and making the doubtful statement that the useful field of application was very limited. Mr. Faraday at least must know better, being a staunch advocate of the Delicolor system, which was operated usually with a high proportion of footlights, battens, and wing floods. His figure of 50 per cent. was probably closer to the mark than the very low figures Mr. Applebee would have led us to believe from his two examples. Mr. Faraday's statement that "the producer had to make a very definite effort to put the artist into the picture and emphasise those artists against the background" was unquestionably correct. It was in the creation of this picture or framework that fluorescent stage lighting could be a powerful tool in the producer's hand. It was equally the function of directional incandescent lighting to "emphasise the artists in various ways in the framework." As regards use on the stage, he was content for time to show the value of both types of equipment, but for many other uses, such as the lighting of auditoria, lecture theatres, cinemas, etc., there could be no doubt as to the value of fluorescent units.

On Mr. Faraday's point about cost it was difficult to give a method for assessing cost because the comparison depended so closely on range of colour and dimming required. One reasonably typical example might be referred to in which initial cost was up by 20 per cent. compared with a corresponding incandescent installation, but this was repaid within three years of normal use.

Mr. Faraday had doubted the statement that it was quite common to fit a 32 blue filter when the final requirement was a No. 18 blue, and had expressed a wish to meet the producer who did that. Without wishing to embarrass the gentleman in question, Dr. Strange said it was the chief engineer of a very large theatre in London, and several other equally experienced people had made the same statement.

Mr. Ruff suggested that insufficient attention was paid to reduction of the lamp

current. This might be attributed to the fact that he had not at that time had an opportunity of studying the paper itself, and in particular Figs. 6 and 7 and the reference to Fig. 14 in section (6). The low current of the lamp in the dimmed condition certainly presented some new problems in dimmer design, but it also represented a great opportunity for saving power and avoiding useless heat. The construction of these new type dimmers, and in fact the general design problems of the equipment, involve many interesting questions of comparative costs which could form the basis of a separate paper at a later stage, but the present one was intentionally restricted to the basic principles and broad features of its application. The author found Mr. Ruff's comments difficult to understand, particularly when in reference to hot cathode lamps he referred to raising circuit voltage while dimming. For cold cathodes he had remarked that the only problem was a sufficiently high supply voltage, but this was surely valid only if there was a resistance dimmer in the secondary circuit, which was usually impracticable. For any other circuit the author would refer him and Mr. Bowtell to a recent textbook ("Cold Cathode Fluorescent Lighting," by H. A. Millar, 1949, p. 61, The Technical Press), where a limit of 10 per cent. was given for the dimming range. Other reports gave a somewhat increased range, but nothing approaching the 0.3—0.1 per cent. of the present circuits.

On the last two points raised by Mr. Ruff, the data given in Fig. 3 and Fig. 9 were for hot cathode lamps, but the curves closely resembled those for cold cathode lamps, such as those of Thayer and Hinman, if these, too, were expressed in terms of relative striking volts. Measurements of this type were very difficult to make because the results were dependent on lamp conditions as well as humidity and the dust on the glass surface, thus the results were only a rough indication of the quantities involved.

If Mr. Bowtell would examine the emission spectra of the phosphors available for discharge lamps he would appreciate that these were in general broad bands determining the colours obtainable, which were not selected according to any preference of the author. Saturated primaries could be obtained, as indicated in the paper, but at the sacrifice of efficiency. Mr. Bowtell was puzzled that some of our negative results regarding the use of krypton were reported as well as our positive achievements. In describing such an investigation the negative results were only secondary in interest to the positive ones, and this particular group of experiments gave a considerable amount of information on the quick-starting properties of lamps.

Most of Mr. Bentham's contributions dealt with the balance of general and localised lighting already referred to. Regarding his suggestion that the distribution of light from a fluorescent fitting must be such as "to allow light to flood indiscriminately," it is interesting to compare these figures for the very compact fitting illustrated in Fig. 16 and a standard incandescent compartment unit.

For the former the total beam spread was 122 deg. and the main beam was at the mid-point of beam spread, the fitting being adjustable on a horizontal axis. The incandescent unit had a total beam spread of 140 deg., and the main beam was at 15 deg. to the horizontal when the bottom of the fitting was laid horizontal.

Some of Mr. Bentham's other statements regarding what fluorescent lamps could or could not do were on a similarly shaky basis. Why, for example, did he state that "to give a full range of blues . . . a three-colour system was essential"? A wide range from dark to light blue could be obtained with two colours only. It should be appreciated that the previous restriction to a few arbitrarily selected stage filters held no longer.

Mr. Williams had a great deal to say about the difficulties of balancing the conflicting demands of the dimming circuit. The author's main reply was that he had succeeded in effecting a satisfactory balance and the life of the lamps was in no way affected. The two things which cut down the life of a lamp most severely were

cold cathode operation and excessive hot spots on the cathode, and both were avoided by the present circuit. Both Mr. Williams and Mr. Misselbrook made the error of assuming that there was a bright glow discharge at the ends due to the cathode heating; the main point was that while there was sufficient current to heat the filaments to emission temperature there was an insufficient voltage drop in the filament to produce a glow discharge. On one other point, a pair of 2-ft 40-watt lamps has a greater dimming range than one 5-ft. 80-watt lamp because they had four cathodes in 4 ft. instead of two in 5 ft. Mr. Williams imagined certain other difficulties regarding capacity effects and radio interference which did not occur. Radio suppression condensers were omitted from the diagrams for simplicity.

Mr. Holmes had raised the two very interesting points of stroboscopic effects and colour rendering. Some trouble had been expected but there had been practically none. One searching test was a stage ice show with the usual high-speed spins but no difficulty had been reported in this, or again for juggling acts. It should be pointed out that combinations of leading and lagging circuits were standard practice.

The efficiency of the 80-watt lamp asked for by Mr. Hilling was 25 per cent. that of the 2-ft. 40-watt. The wire mesh in the fitting was for protection purposes only. The reference by Mr. Misselbrook to the heat emitted from stage lights emphasises a very important advantage of the fluorescent lamp, referred to briefly at the end of Sect. (7). On his other points, the ballast was situated at any convenient point between the fitting and the control board and could be below stage or in "flys" but in any case a properly designed and made choke should have a very low noise level. Dirt was a major problem and might reduce light output by a large amount; the fittings shown had been designed with ease of cleaning as a first requirement.

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The following applicants have been duly elected by the Council to membership of the Society, and their names have been added to the list of members.

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Fellowship

The Council have accepted the following application for Fellowship of the Society:—
M. Gaughan.

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